LHC Project Document No.
LHC-LQX-ES-0001.00 rev 2.3

CERN Div./Group or Supplier/Contractor Document No.
TD/FNAL/USA

EDMS Document No.
108981

the **Large Hadron Collider** project

Date: 2001-05-04

Functional Specification

INNER TRIPLET SYSTEMS AT IR1, 2, 5 AND 8

Abstract

This specification establishes the functional requirements for the inner triplet systems at interaction regions 1, 2, 5 and 8. The specification covers the equipment from the Q1 cryo magnet assembly to the last cryogenic component of the inner triplet. For the high luminosity interaction regions 1 and 5, this includes the Q1, Q2, and Q3 cryo magnet assemblies and the DFBX feedbox, and all associated components. For the low luminosity interaction regions 2 and 8, this includes the Q1, Q2, and Q3 cryo magnet assemblies, the DFBX feedbox, the D1 dipole, and all associated components. This document describes the functional requirements for the inner triplet system as a whole, specifies system parameters, specifies the laboratory which is responsible for each component, and provides a guide to the individual functional specifications for the components that make up the inner triplet system.

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History of Changes

Rev. No.	*Date*	*Pages*	*Description of Changes*
0.1	2000-02-08	10	Submitted for approval.
1.0	2000-03-06	1-10	Approved.
2.0	2000-09-21	4,6-8	Updated corrector nomenclature.
		4,7,10	Refer to optics version 6.2.
		8	Updated number, distribution and strengths of multipole correction layers in Table 4-2.
		5	Added paragraph headings.
		7	Updated list of related Functional Specifications.
		9	Added reference to cryogenic schematics.
		10	Reordered references to match order cited in text.
2.1	2000-11-14	8	Corrector strengths, longitudinal locations, and magnetic lengths updated. Nominal strength of MQXA and MQXB at IR 1 and 5 changed to values for 7 TeV collision optics.
2.2	2001-02-24	7,9,10	Reference made to operation with high-beta optics.
		7	Document number for MQXB Functional Specification added.
		8	Positions of MQSXA and its non-linear layers updated in Table 4-1. Strengths and lengths of MCBXA non-linear layers updated in Table 4-2. (Integrated strengths are unchanged.)
		9	The need to update the heat loads in Table 5-1 is noted.
2.3	2001-04-02	4	BPM moved from non-IP end to IP end of Q2 assembly.
		8	Q2 assembly moved 250 mm away from IP.
		8	Q1 and Q3 magnetic lengths increased and operating gradient decreased to match KEK design.
		4,6	Equipment codes for installed components updated to current nomenclature.
		10	Added additional paper to reference [3].
2.3	2001-05-08	all	Released version

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1.

1. SCOPE

This specification establishes the functional requirements for the inner triplet systems at interaction regions 1, 2, 5 and 8. The specification covers the cryogenic equipment located at each IR: from the warm bore tube flange on the IP side of Q1 to the warm bore tube flange at the DFBX in IRs 1 and 5; and from the warm bore tube flange on the IP side of Q1 to the warm bore tube flange at the LBX in IRs 2 and 8. For the high luminosity interaction regions 1 and 5, this includes the Q1, Q2, and Q3 cryo magnet assemblies (LQXA, LQXB, and LQXC) and the DFBX feedbox, and all associated components. For the low luminosity interaction regions 2 and 8, this includes the LQX assemblies, the DFBX feedbox, the D1 dipole (LBX), and all associated components.

Connections to the DFBX, such as to the cryo distribution line, the room temperature electrical bus work, and instrumentation readout systems, are beyond the scope of this specification.

2. FUNCTIONAL OVERVIEW

The inner triplet system provides the final focusing of the proton beams before collision at four locations in the machine, the high luminosity interaction regions located at IRs 1 and 5 [figure 2-1], and the low luminosity interaction regions located at IRs 2 and 8 [figure 2-2]. The primary hardware difference between the high and low luminosity interaction regions is the use of conventional D1 magnets (LBXW) at the high luminosity interaction regions, and superconducting D1 magnets (LBX) at the low luminosity interaction region, necessitated by the energy deposition to the D1 at the high luminosity IRs.

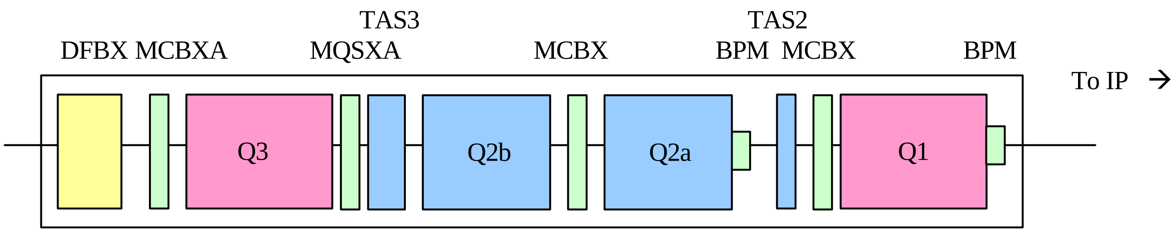

Figure 2-1 Inner Triplet System Schematic, IR1/5

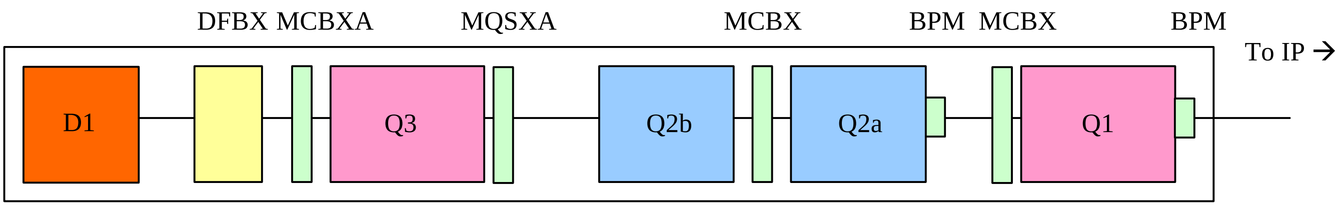

Figure 2-2 Inner Triplet System Schematic, IR2/8

Each inner triplet consists of 3 quadrupole optical elements, Q1, Q2 and Q3, 4 corrector assemblies, MCBX(2), MQSXA, and MCBXA, and a D1, as shown in v6.2 optics [1]. The quadrupoles operate at a gradient of 214 T/m in IRs 2 and 8, and 199 T/m in IRs 1 and 5, at LHC nominal energy and luminosity.

The quadrupoles of the inner triplet focus the beams to small spot sizes, about 0.016 mm at the IPs in IR1 and IR5. At the entrance face of Q1, the beam size increases to more than 0.7 mm and reaches a maximum of 1.5 mm in the triplets. Due to the large beam size and the crossing angle, the beams are subject to non-linear fields of these magnets. The dynamic aperture under collision conditions is largely determined by the field errors in these quadrupoles. Non-linear multipole windings in corrector packages placed in the IRs are needed to compensate the errors in the triplets. The required dynamic aperture is specified to be 12 sigma, as determined by 100,000 turns tracking calculations.

3. SYSTEM COMPONENT ORGANIZATION AND RESPONSIBILITES

3.1 COMPONENT MANUFACTURE

Table 3-1 presents an overview of the responsible laboratories for the components which make up the inner triplet system. CERN is responsible for final assembly of these components in the LHC tunnel.

<u>MQXA, MQXB and Correctors</u>

KEK is responsible for the design, manufacture, acceptance testing, and delivery of the MQXA (Q1 and Q3) cold masses to Fermilab. Fermilab is responsible for the design, manufacture, and acceptance testing of the MQXB (Q2a and Q2b) cold masses. CERN is responsible for the design, manufacture, acceptance testing, and delivery of the MCBX and MQSX corrector elements to Fermilab. Fermilab is responsible for the design and assembly of a 1.9K vessel which includes the above magnetic components.

<u>Cryostats and Assembly</u>

Fermilab is responsible for the design, manufacture and assembly of a cryostat to contain the 1.9K assemblies. Fermilab is responsible for the design, manufacture and insertion of the main bus for all quadrupoles, and for the cold bore within each cryostat. Fermilab is responsible for providing an interconnect kit to CERN, including components for the assembly of the TAS2/3 absorbers and components for connection of all piping excluding the beam tube. Fermilab is responsible for producing the data relating the magnetic axis of the components to fiducials on the external surface of the cryostat. Fermilab is responsible for the delivery of the completed, cryostatted assemblies to CERN.

<u>BPM, RF Connections and Beam Tube Liners</u>

CERN is responsible for the Beam Position Monitors, Beam Tube RF connection, and any absorber or liner which may be inserted in the cold bore of the quadrupoles. CERN is responsible for the assembly of these devices on the delivered cryostatted assemblies.

<u>DFBX</u>

LBNL is responsible for the design, manufacture, acceptance testing and delivery of the DFBX Inner Triplet Feedboxes to CERN.

<u>LBX</u>

BNL is responsible for the design, manufacture, acceptance testing and delivery of the LBX beam separation dipole to CERN.

<u>Alignment Jacks</u>

CERN is responsible for the jacks on which all assemblies are placed, and is responsible for the installation of all components in the LHC tunnel.

Table 3-1 Inner Triplet Responsibilities

Interaction Regions 1 and 5		
Installation Component	Subcomponent	Responsible Laboatory
LQXA		FNAL
	BPMS	CERN
	MQXA	KEK
	MCBX	CERN
TAS2		FNAL
LQXB		FNAL
	BPMS	CERN
	MQXB	FNAL
	MCBX	CERN
	MQXB	FNAL
TAS3		
LQXC		FNAL
	MQSXA	CERN
	MQXA	KEK
	MCBXA	CERN
DFBX		LBNL

Interaction Regions 2 and 8		
Installation Component	Subcomponent	Responsible Laboatory
LQXA		FNAL
	BPMS	CERN
	MQXA	KEK
	MCBX	CERN
LQXB		FNAL
	BPMS	CERN
	MQXB	FNAL
	MCBX	CERN
	MQXB	FNAL
LQXC		FNAL
	MQSXA	CERN
	MQXA	KEK
	MCBXA	CERN
DFBX		LBNL
LBX		BNL

3.2 RELATED COMPONENT DOCUMENTS

Detailed documentation of each of the components and associated interfaces will be available as they are developed. The Inner Triplet Functional Specification contains an overview of the system design and pertinent system information required by others in the LHC project.

For details of the components in the inner triplet system refer to the following documents, as they are completed:

Beam Separation Dipole Functional Specification [LHC-MBX-ES-0001.00]

DFBX Functional Specification [LHC-DFBX-ES-0100.00]

LQX (Q1, Q2 and Q3) Functional Specification

MQXA (KEK Inner Triplet Quadrupole) Functional Specification

MQXB (Fermilab Inner Triplet Quadrupole)
Functional Specification [LHC-LQX-ES-0002.00]

MCBX Functional Specification

MCBXA Functional Specification

MQSXA Functional Specification

TAS 2/3 Functional Specification

Inner Triplet Beam Position Monitor Functional Specification

4. MACHINE OPTICS

The inner triplets are depicted in v6.2 of the LHC optics layout [1].

A summary of the pertinent magnet parameters is given in Table 4-1. The strengths listed are, in the case of the dipole and quadrupoles, for nominal LHC operating conditions of 7 TeV and standard optics. The powering system (see section 6.1) offers the flexibility of independent powering the three inner triplet quadrupoles, which in turn allows high-beta optics[2]. The gradients in this case are all lower than those shown in Table 4-1.

The corrector assemblies consist of a series of layers as shown in Table 4-2. The nominal strength of each correction element[3] is also shown in this table.

Table 4-1 Magnetic Components of the Inner Triplets

Interaction Regions 1, 5				
Component	Nominal Strength	Magnetic Length	IP to Mag. Center	
MQXA (Q1)	197 T/m	6.37 m	26.15 m	
MCBX	Table 4-2	Table 4-2	29.86 m	
MQXB (Q2a)	199 T/m	5.50 m	34.80 m	
MCBX	Table 4-2	Table 4-2	38.05 m	
MQXB (Q2B)	199 T/m	5.50 m	41.30 m	
MQSXA	Table 4-2	Table 4-2	46.91 m	
non-linear correctors			46.67 m	
MQXA (Q3)	197 T/m	6.37 m	50.45 m	
MCBXA	Table 4-2	Table 4-2	54.10 m	
non-linear correctors			54.30 m	[a]

Interaction Regions 2, 8				
Component	Nominal Strength	Magnetic Length	IP to Mag. Center	
MQXA (Q1)	212 T/m	6.37 m	26.15 m	
MCBX	Table 4-2	Table 4-2	29.86 m	
MQXB (Q2a)	214 T/m	5.50 m	34.80 m	
MCBX	Table 4-2	Table 4-2	38.05 m	
MQXB (Q2B)	214 T/m	5.50 m	41.30 m	
MQSXA	Table 4-2	Table 4-2	46.91 m	
non-linear correctors			46.67 m	
MQXA (Q3)	212 T/m	6.37 m	50.45 m	
MCBXA	Table 4-2	Table 4-2	54.10 m	
non-linear correctors			54.30 m	[a]
MBX (D1)	3.55 T	9.5 m	63.11 m	

Note [a]: Preliminary longitudinal location of non-linear layers.

Table 4-2 Corrector Packages of the Inner Triplets

Corrector Package							
MCBX (Q1)				MCBX (Q2)			
Corrector		L_{mag} (m)	Field (T @ 17 mm)	Corrector		L_{mag} (m)	Field (T @ 17 mm)
MCBXH	b1	0.45	3.3	MCBXH	b1	0.45	3.3
MCBXV	a1	0.48	3.3	MCBXV	a1	0.48	3.3

Corrector Package							
MQSXA (Q3)				MCBXA (Q3)			
Corrector		L_{mag} (m)	Field (T @ 17 mm)	Corrector		L_{mag} (m)	Field (T @ 17 mm)
MQSX	a2	0.22	1.36	MCBXH	b1	0.45	3.3
MCSSX	a3	0.13	0.11	MCBXV	a1	0.48	3.3
MCOSX	a4	0.14	0.048	MCSX	b3	0.61	0.015
MCOX	b4	0.14	0.045	MCTX	b6	0.62	0.010

5. CRYOGENIC SYSTEM

All superconducting magnets of the inner triplets, including the D1 in IRs 2 and 8, operate at a nominal temperature of 1.9K. In Table 5-1 the 'installed capacity' requirement for each side of each inner triplet system is shown, calculated using the guidelines in [4].

Details of the static and dynamics loads, component by component, used to generate this table are presented in [5]. *Note, the heat loads are currently under review. New values, which may be up to 15% larger than shown here, will be included in the next revision of this specification.* The cryogenic flow schematics are found in [6].

Table 5-1 Inner Triplet Heat Loads and Installed Capacity Requirements

	Installed Capacity Required (W)		
	70K	4.5K-20K	1.9K
IP1 Nominal Heat Load	785	170	185
IP1 Ultimate Heat Load	785	205	420
IP1 Installed Capacity	1180	300	425
IP2 Nominal Heat Load	845	130	60
IP2 Ultimate Heat Load	845	140	95
IP2 Installed Capacity	1265	240	105
IP5 Nominal Heat Load	785	170	185
IP5 Ultimate Heat Load	785	205	420
IP5 Installed Capacity	1180	300	425
IP8 Nominal Heat Load	845	130	60
IP8 Ultimate Heat Load	845	140	95
IP8 Installed Capacity	1265	240	105

6. ELECTRICAL SYSTEM

6.1 MAGNET POWERING

The inner triplet quadrupoles are powered in a 'mixed' mode, which allows for an economical powering of the MQXA and MQXB magnets in each triplet given the range of powering options foreseen for the triplets, allowing both for a common gradient in all quadrupoles as required for the standard optics, or independent gradients as required for high-beta optics[2]. A schematic of this powering scheme is shown in Figure 6-1.

The MCBX and MQSX correctors, and associated layers, are independently powered. All bus work is routed out of the inner triplet system through the DFBX feed boxes, and complete lists of the electrical connections for the inner triplet systems can be found in the DFBX Functional Specification.

6.2 MAGNET PROTECTION

The inner triplet components will contain protection instrumentation compatible with the CERN-supplied quench protection system. Power leads, bus work and magnets will be instrumented with voltage taps with wire cross sections and insulations compatible with the CERN Instrumentation Specifications [7]. CERN will provide

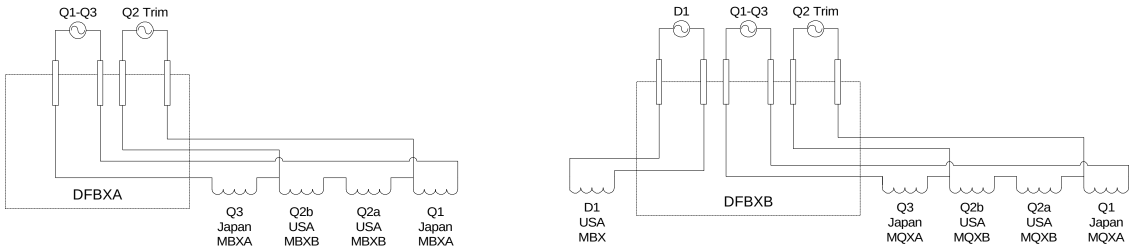

Figure 6-1 Inner Triplet Powering Schemes for the High and Low Luminosity Interaction Regions

similar protection for the correction elements. MQX and MBX magnets with be equipped with protection strip heaters. Requirements for strip heater currents and voltages are within the operational specifications of the CERN supplied heater power supplies [8]. Heater withstand voltages are specified in [9]. Voltage tap and quench heater leads are all routed through the DFBX.

6.3 OTHER DIAGNOSTICS

Instrumentation required to control the inner triplet cooling system, such as temperature pressure and liquid level sensors, and heaters, will be installed by the laboratory responsible for the component in which they are installed. These instrumentation leads are routed through the DFBX, except for those located in the cryostat vacuum space which will be routed locally through the cryostat vacuum vessel.

7. REFERENCES

1. "LAYOUT OF LONG STRAIGHT SECTION, V6.2," LHC Drawings LHCLSX__0001 and LHCLSX__0002 (IR1); LHCLSX__0003 and LHCLSX__0004 (IR2); LHCLSX__0009 and LHCLSX__0010 (IR5); LHCLSX__0015 and LHCLSX__0016 (IR8).

2. A. Faus-Golfe, "Optimized high-β insertion optics for the TOTEM experiment in IR1 and IR5 for Ring 1 and Ring 2 of the LHC Version 6.0, LHC Project Note 207, November 1999.

3. J. Strait, "IR Corrector Studies," Fermilab TD Note TD-00-058, 20 April 2000; V. Ptitsyn, et al., BNL Collider-Accelerator Department note C-A/AP Note 21, December, 2000.

4. "LHC SECTOR HEAT LOADS AND THEIR CONVERSION TO LHC REFRIGERATOR CAPACITIES," LHC Project Note 140, May 1998.

5. "ESTIMATE OF THE NOMINAL AND ULTIMATE CRYOGENIC CAPACITY REQUIREMENTS FOR THE LHC INTERACTION REGIONS," Fermilab TD Note 99-041, 10 September 1999.

6. "DFBX FLOW SCHEMATICS," LHC Drawing LHCDFBX_0001.

7. "INSTRUMENTATION IN THE LHC INTERACTION REGIONS," LHC Specification in preparation.

8. "TECHNICAL SPECIFICATION FOR THE SUPPLY OF HEATER DISCHARGE POWER SUPPLIES," LHC Specification in preparation.

9. "VOLTAGE WITHSTAND LEVELS FOR ELECTRICAL INSULATION TESTS ON COMPONENTS AND BUS BAR CROSS SECTIONS FOR THE DIFFERENT LHC MACHINE CIRCUITS," LHC-PM-ES-0001-00-10, 18 May 1999.